Better Perception of 3D-Spatial Relations by Viewport Variations

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Abstract. Computer-graphics and especially virtual 3D worlds evolve to important tools for digital cartography, where the main aim of efficient spatial communication rules processes of conception, design and dissemination. This paper investigates the enhancement of visual spatial relations in virtual 3D worlds, which's limitation on standard displays is a main drawback of digital cartography. The main limitations of digital cartography concern the extension of viewing plane and its resolution, which have impact on information depth of the map content, transmitting an overview, thus the highlighting of spatial relations and additional request for cognitive load. These drawbacks are not only limited to 2D maps, but are also existing in virtual 3D environments, where additional geometric characteristics, like perspective distortions, multiple scales or overriding, may influence a correct extraction of spatial-related content. On the other hand these specific geometric disadvantages should be formulated as benefit of 3D, especially when infinite numbers of scale can be combined in a "natural way" or spatial content becomes extracted by naïve interaction. One main limitation of digital presentations generally persists: the limitation of the presentation area on standard displays, which leads to a very restricted overview and fewer visible relations of spatial content. View-port variations that modify perspective and/or orthographic projections are one possibility to enhance rendering methods in a way that the main disadvantages of regular perspective views become decreased and the perceptibility for an overview and spatial relations expanded. These variations cover progressive and degressive central-perspectives as well as progressive and degressive "parallel-perspectives", which provide very specific characteristics in use with spatial information transmission. This contribution focuses on enhancing virtual spatial relations in 3D environments by using view-port variations, that modify perspective and orthographic views in a progressive and degressive way. Provided that standard displays deliver significant limitations for effective and expressive geo-communication with virtual 3D environments, offers by 3D cartography are discussed. An exemplary comparison of actual 3D city models allows to identify "dead values" and gives one clue for the requested modification. The description and exemplary visualization of view-port variations lead to their theoretical communication aspects, which will guide pragmatic (user) studies in future.

Keywords: 3D geovisualization, geo-mediatechnique, perception, graphical design, geo-communication

1 Introduction

Virtual 3D worlds deal as important tool for digital cartography. Especially when the metamorphosis of paradigms becomes accepted in the field of cartography and the "new" task focuses on a successful geospatial communication, virtual 3D worlds play their part for the conception, design and dissemination of spatial information. Virtual 3D worlds seem to be attractive for a wide public community and thus form an important communication tool. In fact virtual 3D worlds support some kind of naïve geography [1] and can enhance the understanding of topographic relations with low experience or spatial knowledge [2]. Spreading web applications, like Google Earth, Virtual Earth or World Wind, support the thesis that virtual 3D worlds are naively understood. At least these kind of geographic applications support cartographic issues and expand the working field of digital cartography in a way that visual spatial relations within the display presentation are more easily perceived, if certain limitations can be identified and further on reduced. Thus this contribution focuses on how visual spatial relations in virtual 3D worlds can be enhanced and certain limitations of their visualization can be reduced.

Virtual 3D worlds as add-on for digital cartography will have to follow semiotic requirements, which allow to identify map elements clearly. According to this requirement, virtual 3D worlds may deal as 3D cartography that generally offers extensions to digital cartography, although massive restrictions exist from another point of view. These specific "geometric disadvantages", such as perspective distortions, multiple scales or overriding, should be considered as benefits of 3D. Then these specific characteristics of 3D propagate the keeping of spatial relations for navigation and tasks of spatial literacy. Although the specific characteristics are generally used by virtual 3D environments, main disadvantages are observable in actual examples of virtual 3D cities. These observations lead to viewport variations with the purpose to extend perspective views in a way that spatial relations become enhanced, landmarks show up directions, prospective routes are not hidden and geometric values are easily comparable. A simple realization with two bending ground plates demonstrates applicability in real-time 3D environments. This technical solution does not consider any impact of this newly created presentation form for virtual 3D environments. This discussion will be subject to future research. But this way of thinking shows up one possibility to overcome some restrictions of digital cartography without changing the techniques of actual transmitting interfaces.

2 Restrictions of digital cartography

Digital techniques have fundamentally changed the field of cartography. Not only in the area of reproduction, but especially in terms of dissemination and user participation. In combination with the Internet almost everyone is able to reproduce and disseminate map pictures. In addition large amounts of geospatial data become accessible and can be used by everyone, who knows how to deal with simple webmapping techniques. In most cases these data are not appropriate and result in very poor maps, especially when some processing of data harmonisation and specific coding are left out. Generally professional mapmakers know how to modify geospatial data for digital cartography and displays. These use cases follow expanded cartographic rules due to specific characteristics of transmitting media [3, 4]. In any case digital approaches in cartography lead to a more extensive dissemination of geospatial phenomena, to a global management of various data (e.g. Public data of UN or NASA) and to user participation in recording geospatial data in form of GPS tracks (e.g. www.openstreetmap.org) or leaving spatial tags.

In spite of all the advantages in dissemination, data management and user participation, digital cartography comes along with restrictions due to specifics of the transmitting media “display”, which is mostly used. The restrictions of the content concern overview and resolution as source elements that provoke higher cognitive load on one hand and loss of spatial relations on the other. In comparison to analogue media, like paper, digital media are restricted in their extension of the view plane. Whereas paper maps have been printed on sheets up to A0 (~84 x 120 cm), actual displays for digital cartography reach an extension of about 30 x 40 cm. Extraordinary large displays, as these are used for HDTV in home cinemas, will bring a higher extension of the viewing plane, but do not increase resolution in a way it would be useful for digital cartography. In the same way projectors (beamers) result in a large viewing plane. Their resolution is fixed to standard display resolutions (VGA, SVGA, XGA). Thus the size of the projected picture element increases and becomes clearly visible if the viewing distance is not changed. Therefore the information content cannot be increased compared to the standard display. Instead the viewing distance has to be increased in order to perceive a homogeneous presentation. As result we can conclude that the extension and resolution is closely related and is generally not significantly more than 2000 x 1500 pixel (picture elements) on an area of about 30 x 40 cm. The resolution of 2000 x 1500 pixel cannot carry more geospatial information than a printed map of about 17 x 12,5 cm size, when 300 dpi are used for the printing process (!) [5]. Lechthaler speaks of a ratio 1:3 for a dual system that uses print and display media.

The restrictions of information content are not that strong, that digital media are useless for maps. The reason is that appropriate interaction with media can overcome information restrictions with operations like zooming, panning and mouse over interaction. Zooming allows receiving more detail when zooming in or get some overview when zooming out. Both operations come along with changes of information content in order to keep perceptibility and semantics of the presentation. Panning moves the map picture at the same scale with the aim to change the map focus or to explore spatial relations around a map focus, whereas the map focus names an interesting area of a map. Mouse over interaction allows embedding visual hidden information and thus compresses information content. Although all these simple operations help to overcome restrictions of digital media, the cognitive result at the user side is not promising. The reason is that every operation calls for cognitive load and specific attention, which deflects the user from information extraction. Receiving some overview and extracting spatial relations is a challenge due to zooming, panning and mouse over events. We can conclude that digital cartography still lives with the main drawbacks in terms of restricted content (resolution and extension), increasing cognitive load to overcome content restrictions and according to this a cognitive challenge to extract a promising overview and spatial relations.

3 What 3D cartography can offer?

Virtual 3D environments with cartographic pretensions are not an overall solution for digital cartography, but provide some aspects that help for the specific tasks of overview and spatial relations. From a geometric point of view 3D environments come along with geometric characteristics, such as perspective distortions, multiple scales or overriding, that influence a correct extraction of spatial-related content. These geometric disadvantages can be considered as benefits of 3D, especially when infinite numbers of scales can be combined in a "natural" way or spatial content becomes accessible by naïve interaction in the virtual world.

Combinations of multiple scales due to perspective view complicates a single identification of elements throughout the depiction, but reconstruct a natural view for humans, which helps to accept the virtual 3D environment as virtual reality. According to rules of depth perception [6], elements will be identified by cognitive processing as long as similar geometric elements exist and the perspective view is homogeneous. The main advantage of scale combination is the direct and intuitive comparison of large and small scales, which would be possible in neither a large nor small scale alone. Especially when details of a large scale are directly related with far objects, a visual solution seems to be impossible. For example architectural details in a wall that are related with specific buildings on the other side of a city will be visible in nature, but not in single scale maps. The creations of virtual 3D environments with their geometric characteristics help to rebuild reality and these relations again. Especially historic analysis, when buildings do not exist any more, call for reconstructions like these in order to identify spatial architectural relations. If these relations should be discovered in large scale maps, their extension would be to big for an exact angle extraction and a cognitive relation reconstruction (mental map). If the maps are in a small scale, so that the extension is not that large, their details will have to be generalized and are not perceivable any more. With examples like these we can conclude that virtual 3D environments enhance specific spatial relations, which affect various scales in the depiction.

In addition to the spatial relation enhancement, the camera grades of freedom (translation, rotation,..) support the naïve extraction of spatial information. As long as the camera movement and rotation follows "natural" movement metaphors, users are able to identify and interact with the virtual world in a naïve way. Natural movement metaphors rebuild functionality of movement in reality, like walking or moving the head. An interface that allows uses the same actions (walking, head movement) will have the highest impact. With some experience, humans are able to automatically translate mouse interaction to their natural spatial movement, although this translation requires enormous cognitive load, as long as mouse movement follows the natural movement metaphors.

The enhancement of spatial relations and natural movement metaphors are fundamental for a naïve geography as it is incorporated in virtual 3D environments. Following the definition of naïve Physics by Hardt (1992) and the extension by Egenhofer and Mark (1995) the notion naïve geography names "the body of knowledge that people have about the surrounding geographic world" [7, p. 4]. By this meaning naïve describes an instinctive and spontaneous approach by the user, who will search for operational and cognitive structures that match the individual structures when exploring space. Virtual space then forms one part of virtual geographic space that is represented by various geometries and scales beyond the virtual camera. Therefore virtual geographic space cannot be observed from one single viewpoint [8] and relies on natural movement metaphors for exploration within the virtual 3D environment. The cartographic representation, which is an "enhanced" virtual reality in terms of perceptibility of graphical values and the semantic consistency of map elements at various scales, delivers a more real experience than movement in reality. According to Egenhofer and Mark (1995) map-based, map-like or enhanced views of geographic space give a better representation and support a naïve assumption of where one moved through geographic space. This conclusion bases on the statements of users like "..when I get home, I want to look at the route on a map, to see where I went..." [7, p. 8]. Nowadays these people often use Google Earth as easy accessible mapping tool for the visualization and global exchange of their tracks.

Considerations above lead to the conclusion that 3D cartography on one hand enhances users identification with their access to naïve geography and the user's recording of visual spatial relations and on the other hand enable naïve interaction with natural scale combinations. Natural movement metaphors with their direct access to knowledge structures of the user support this conclusion. Naïve geography in our case of virtual 3D environments basically focuses on a movement in virtual space and explorable virtual spatial structures and does not concern GIS functionality or analysis, which may mislead user's knowledge supplement depending on existing experiences and world knowledge [9].

4 Importance of virtual spatial relations

The argument that natural movement metaphors and naïve interaction help to directly access individual knowledge structures at the user side bases on the assumption that reference points, -lines and -areas provide virtual spatial relations, which are at least partly known and help to navigate, explore and extract knowledge in virtual 3D environments. These reference elements serve as virtual landmarks that are key factors for orientation within the virtual world.

Virtual worlds are often misleading and very restricted for the communication of spatial topologies if we look on examples of the gaming industry. A lot of ego-shooter games make use of 2D maps in order to give some rough overview and directions for the movement, although theses little raster maps are very restricted in resolution and extension. Darken and Cevik (1999) describe orientation issues of maps that are used in ego-shooter games. The results showed that for the purpose of navigation in 3D environments the forward-up treatment of the 2D map was the most promising. What Darken and Cevik did not enlighten at this point – it was obviously not the main focus of the paper – was the characteristic of massive overriding within these ego-shooter games. One can hardly see the second row of buildings. This fact restricts the use of landmarks for orientation and of course calls for 2D maps as orientation and wayfinding help.

Landmarks or visual references are used in real and electronic spaces. These elements are mainly used to form the cognitive map of the realistic or electronic/virtual environment and are characterized by their extraordinary features that help to recognize and memorize these features in the environment [10]. Sorrows characterizes landmarks by singularity, prominence, meaning and category. Singularity of the object describes the sharp contrast with its surroundings as regards to visual attributes. Also for Lynch (1960) singularity is the most important characteristic. A landmark is visual flashy when this building/element differs from its immediate surrounding concerning its size, shape, age or cleanliness. Prominence focuses mainly on the spatial location. For instance a building's shape is visible from various locations or it is located significantly at a junction. Meaning qualifies the content of a landmark in terms of cultural importance. Similar attributes of objects may lead to a general used category, which does not relate to a specific location but to a situation. For example a white church in a village center as specific landmark is assigned to other villages as category for town church and the center for the village. In addition to visual attributes, landmarks in virtual 3D environments obtain various kinds of interactivity, which can transform passive visual landmarks to active landmarks. Active landmarks may not be differentiated by visual attributes, but become active by user nearness or interaction, which allows for relieving transmitting interface with its graphical values.

Visual landmarks in a virtual 3D environment are one of three main levels for spatial knowledge. In order to construct a cognitive map, which is the first step in creating spatial knowledge that enables (virtual) spatial movement, the three levels of landmark knowledge, procedural knowledge and survey knowledge have to be acquired [11]. Landmark knowledge represents landmark characteristics for a specific location/area in an environment. The recording of visual landmarks and their topology is done by exploration. Procedural knowledge encodes as navigation actions along a route. It includes perceptual features along the way, which concern distances between locations and turns along the route. Survey knowledge enables a user/traveller to mentally draw an explored region from bird's eye view and to navigate with confidence. According to Elvins (1997) survey knowledge is generally gained from map study or prolonged exploration/movement in an environment.

The importance of visual landmarks and spatial relations in a virtual 3D environment for navigation, wayfinding and spatial knowledge expansion leads to the question, if actual standard perspectives deliver the best perception for 3D-spatial relations in virtual 3D environments. Therefore standard perspectives´ originalities should be evaluated.

5 Evaluating standard perspectives

The depiction of a virtual 3D environment on the transmitting interface/media is rendered according to viewport attributes. These attributes define a cameras orientation, distance and field of view (FoV) in case of perspective views, and camera orientation and orthographic height in case of parallel projections. Depending on these camera's attributes and a transmitting interface's resolution the amount of dead values changes. Dead values describe information pixels that are not appropriately used for information transfer. This means that the content of pixel cannot be related to an specific element or the overall visualization content. Due to a restricted amount of pixels for an information transfer, a most efficient use of these pixels is the aim.

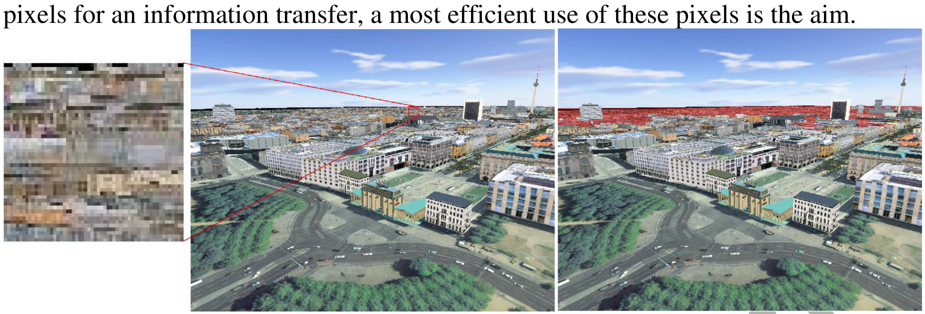

Fig. 1. The area of dead values in a central perspective view is marked red in the right picture. The picture on the left shows this "undefined" pixel area in detail.

Central perspective views combine linear perspective and multiple scales in one view, which leads on one hand to geometric distortions of the elements and on the other hand to a high variance of element sizes (on the presentation plane/viewing plane). Geometric distortions of elements assume that more than one element of the same sort exists in the view in order to retrieve geometric relations (size, primitives, ...). The high variance of scales enables the direct comparison of large and very small scales in one directed view, but also leads to dead values if elements fall below the resolution of transmitting media. If this uniqueness-relation between transmitting media and content element is larger than one, a single picture element of transmitting media has to represent several pixels of the content.

Parallel perspective views offer one single scale throughout the view, which allows a direct comparison of element sizes and orientation. Due to the isometric character of this view, the scene seems to arch upward in the background. Actually the geometric correct characters of parallel perspectives create discrepancies with the human cognitive system, mainly because of the three main rules of composition stability [12, 6, 13]. Thus the main disadvantage is its disturbance of naïve perception. The main advantage lies in a scale dependent illustration.

In case of standard perspectives we can conclude that their use of transmitting media's viewplane for virtual 3D environments is not perfect. Due to dead value areas for various camera parameters the requirements of cartography-oriented design are mainly not met. In order to reduce these areas, viewport variations show one possible approach.

6 Extended perspectives by viewport variations

A variation of viewport perspectives follows the aim to reduce dead value areas and thus improve the use of transmitting media's viewplane. This approach is guided by syntactic considerations in terms of expressive geospatial communication. It does not concern effects of semantics and pragmatics, which also influence the composition of virtual 3D environments. Hence the following collection of perspective variations is evaluated by their impact on dead value areas, communication of spatial relations and its syntactic dimension.

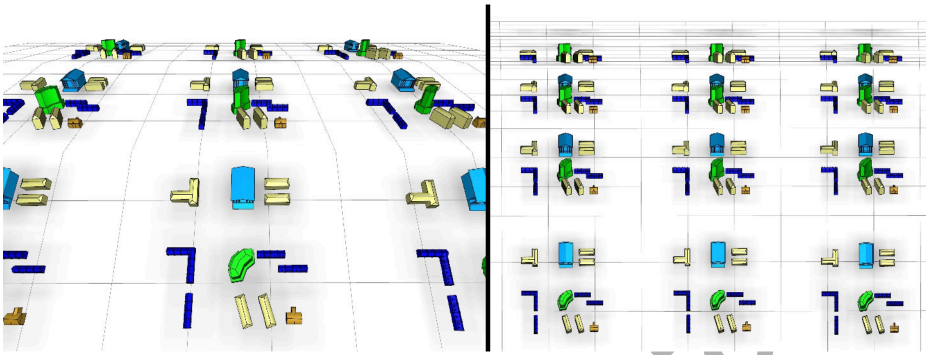

Fig. 2. Conceptual view of a progressive central perspective and progressive parallel perspective.

The progressive approach intensifies perspective impression by forcing ground-view zones nearby the camera and front-view zones for far elements. This means that the perspective view becomes arranged depending on the distance to the camera. The grouping to "view angle" zones enables the specific element enhancement in that zone. For example a ground-view generally delivers footprints that are combined with very restricted front-view information. In this situation it is important to keep the footprint information by its semantics, which will lead to highlighting and aggregation for specific scales. On the other hand in an front-view zone the footprint almost disappears. The main transferred information is build up by the upright projection. Therefore the front-view and its semantic/outline has to be highlighted for specific, orientation enabling elements.

The Progressive Central Perspective makes use of "view angle" zoning that allows for element adjustment according to the view angle of viewport camera. In addition its perspective impression becomes intensified. The enhancement of the ground-view in the foreground presents an overview around the current camera position, which mainly relies on buildings footprints and topographic relations. The force for front-views in the background enhances visual landmarks by their front-view. An highlighting of important/outstanding and well known elements directly supports the usage of landmarks for orientation within the virtual 3D environment. Spatial relations between the foreground's overview and the background's landmarks are strengthened, especially because standard perspectives will not provide the extension (on the transmitting interface) to show both.

Progressive Parallel Perspective uses the same constellation of "view angle" zoning and results in the same argumentation for using ground-view and front-view situations. Additionally its metric constitution, which disturbs a naïve perception, gets some "perspective" character. Thus the parallel perspective can use its metric and simulates perspective characteristics.

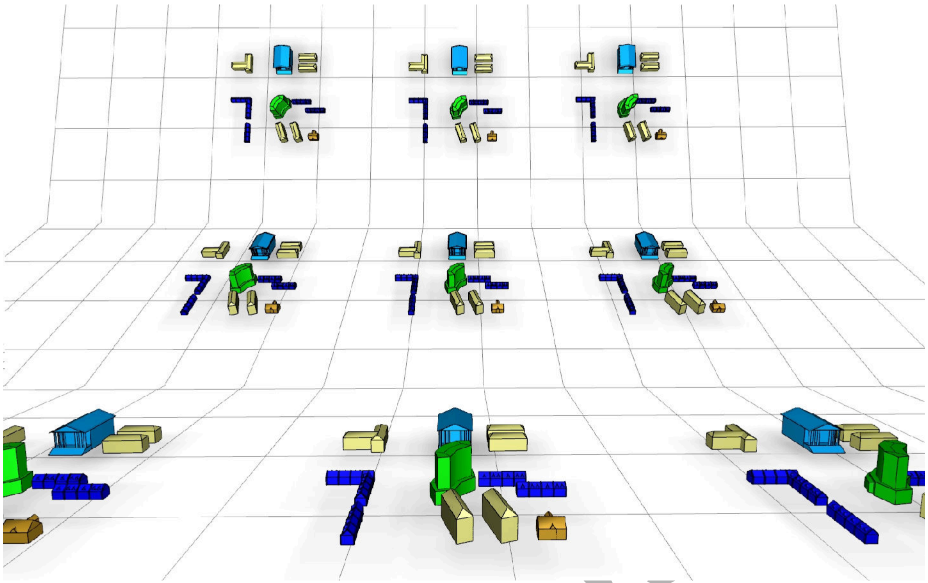

Fig. 3. Conceptual view of a degressive central perspective.

In contrast the degressive approach with a Degressive Central Perspective generally destroys any naïve perspective perception by its use of front-view zones in the foreground and ground-view zones in the back. Its aim is to simulate user's perspective at the camera's position in order to generate high identification in the specific area and deliver an overview of the prospective tour at the same time. The request in this case is a high detailed model in the front and a scale-dependent map design in the back. The rendering style definitely has to change in order to reduce confusion when a map is used instead of clouds and sky.

All viewport variations have in common that dead values on the transmission interface become minimized. The reason is that "view-angle" zones reduce the infinite number of scales to several groups and therefore allow for specific element generalization. The information transmitting area theoretically becomes more appropriate used according to its purpose (generating an overall overview with naïve geography or supporting navigation in virtual 3D environments). As result of this reduction of dead values and a more extensive use of transmission interface, spatial relations are enhanced as well (because more information pixels are available for overview generation).

By reason that theoretical considerations are often not realizable or result in main drawbacks of graphical processing capacities, an exemplary realization of viewport variations for real-time applications is added.

7 Simple exemplary realization for real-time applications

A simple example of viewport variation for real-time applications was realized by a bendable ground plate that amplifies ground- and front-view. Both parts of the plate are connected with a transition zone, which shows up as concave molding. Because this concave molding with bended buildings disturbs acceptance at the user, its area should be minimized. The use of this transition zone is a homogeneous change from ground- to front-view zone.

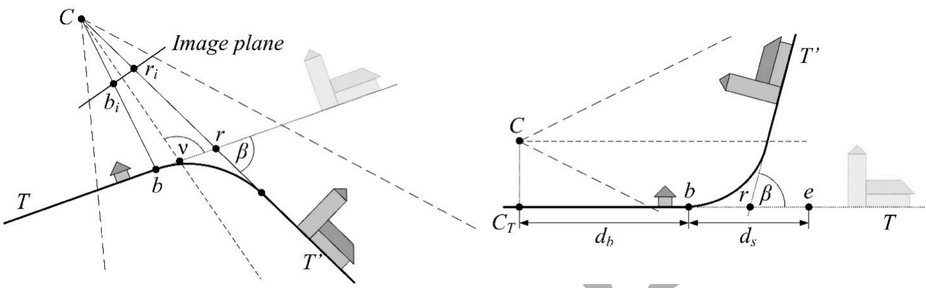

Fig. 4. Simple progressive and degressive concept of a bending ground plate, based on Lorenz et al 2008.

The deformation for the viewport variation is implemented as task for the GPU (Graphical Processing Unit). The processing scheme does not introduce new vertices. The curved transition zone can show up rendering artefacts due to insufficient tessellation. This setting allows a straightforward solution, where a LoD (Level of Detail) algorithm selects more detailed object representations within the transition zone [14].

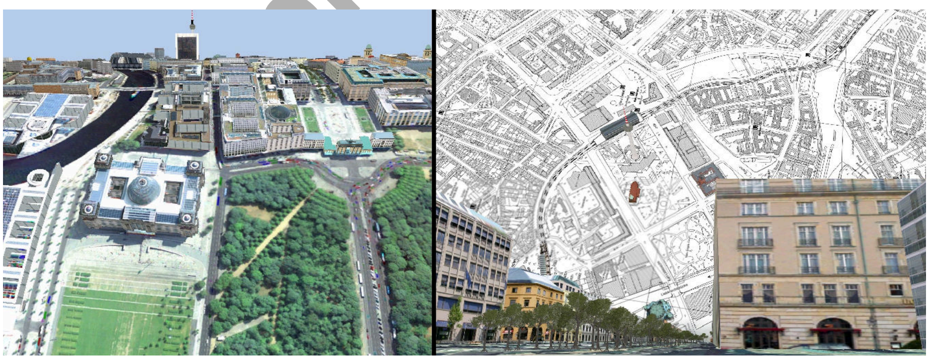

Fig. 5. Simple progressive and degressive views, rendered with LandXPlorer, based on Lorenz 2008.

The rendering frame rates for the real-time environment are mainly resolution independent. The access to textures can be identified as main bottleneck in the test application. An out-of-core algorithm was used to load texture on demand in sufficient resolution from the disk. Progressive perspectives come along with exceptionally high load rates, which are caused by the visible horizon. More terrain and elements become visible. Their low quality does almost not influence the loading process. In degressive perspectives only a part of the terrain and elements are visible compared to standard perspective views. The ground-view texture in the background leads only to a slight reduction in texture load [14].

This exemplary realization demonstrates applicability of preceding theoretical considerations. The implementation bases on global space deformation that is processed by graphics hardware. It permits the seamless combination of different graphical representations.

8 Conclusion

We can conclude that viewport variations enable a better perception of 3D-spatial relations. The variation of perspectives to progressive and degressive as well as central perspective and parallel perspective improves the usage of information pixels of transmission interface. Dead information values can be reduced. Due to "view-angle" zones specific enhancements of elements can be adapted more easily, which supports unambiguous perception of information content. The progressive as well as the degressive character expands the overview of the virtual 3D environment. By this means 3D-spatial relations can be accentuated in an impressive way.

Future work will have to focus on semantic and pragmatic dimension of viewport variations. Whereas degressive perspectives´ implementations for navigation systems are imaginable, their impact on users´ cognitive processing and the resulting mental model has to be proven. It may be that the resulting mental relations do not match with reality. But there also exits the chance that this presentation forms support cognitive processes and improve spatial literacy.

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